Machinery Health Monitoring – Sense & Respond Logistics

All eyes fixed on the future, the United States Navy looks to extend condition-based maintenance (CBM) technologies into the supply chain.

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THE VISION

In the year 2015, on some future naval platform–perhaps USS BLUE SKY–a machine will begin to falter in one of its pre-defined failure modes. This automatically will trigger a series of events to correct the failure and update the mission-readiness status of the platform in real-time. The "trigger" for some failure modes will, in fact, precede the actual functional failure, thus allowing for mitigating action to prevent an unplanned failure. This includes the pre-ordering of parts to complete necessary (and timely) maintenance without the inccurring of unnecessary logistics delays.

The type of early warning outlined for the futuristic USS BLUE SKY also will allow a commander to assess the potential risk of the impending failure against the mission profile. That's because a pre-validated, engineered work-order candidate, residing in a current or future database, will contain the required configuration data to identify the parts and tools necessary to accomplish the repair. In turn, the ship that work-order candidate is on will no longer be required to carry a large load of contingency spare parts, since the trigger mechanism will provide ample lead time for those parts to be put into the supply chain.

Building blocks for the adjacent sidebar's "BLUE SKY" vision of the future are in-place now – yet, much still remains to be done. Why should we do it?

The answer lies in existing Chief of Naval Operations (CNO) policy and validated requirements for future naval platforms. Navy and and Department of Defense (DoD) initiatives, such as SHIPMAIN, CBM Plus, Engineering for Reduced Maintenance, Sense and Respond Logistics, Focused Logistics, and various Future Naval Capabilities provide vehicles and, in some cases, resources to achieve this future vision.

The Navy's Integrated Condition Assessment System (ICAS), as the program of record for shipboard machinery condition monitoring, provides the technology insertion opportunity to advance CBM and Sense and Respond capability. There is no silver bullet in any of the aforementioned efforts. Acquisition managers and technical warrant holders need to skillfully steer the work of these diverse, but related efforts, and harvest the offerings that support the requirements. There have been and will be successes to build upon, and there will be disappointments along the way. With no ready-made solutions available, there needs to be continued investment, engineering and trials, demonstrations and incremental fielding of advances via spiral development. The advances that are fielded will come largely from operating within the current framework of programs, organizations and policies.

Background

The case for condition-based maintenance (CBM) has been made. CNO effectively ended any debate in 1998 by issuing OPNAVINST 4790.16 (Condition Based Maintenance Policy). This instruction extended the more limited 1992 CBM directive (OPNAVINST 4700.7J) by mandating CBM application to all naval platforms.

The intelligent application of sensing, processing and decision support technologies has a significant role in supporting Navy CBM policy. In the intervening years, there has been significant R&D investment in enabling technology, resulting in incremental improvement of fielded technologies and the associated maintenance and logistics applications, including, but not limited to, the previously referenced ICAS, the shipboard Preventive Maintenance System (PMS) Scheduler (SKED) and the Organizational Maintenance Management System–Next Generation (OMMS-NG). What has been missing is a tight integration between systems and linkage to supporting logistics and supply chain applications.

Navy enterprise resource planning (ERP) implementation is on the horizon. However, as of this writing, (October 2005), there is no afloat ERP template.

Application integration, to include available commercial off-the-shelf (COTS) products through development of software adapters, provides the vehicle to improve effectiveness and efficiency of today's legacy applications onboard fielded platforms. Integration also will provide a stepping stone to the future of seamless information exchange among maintenance, logistics and operational readiness applications, both afloat and ashore.

Development and acquisition of CBM-enabling technologies must follow the same reliability-centered maintenance (RCM) engineering principles of applicability and effectiveness as those used for development of maintenance requirements and tasks. A key concept is illustrated in Fig. 1, which plots resistance to failure versus operating age. In summary, a CBM enabling technology needs to be able to sufficiently detect the onset of a dominant failure mode (*Potential Failure*) in advance to prevent *Functional Failure*. In cases where this may not be possible–either due to the nature of the failure and/or limitations of the technology–there may still be value in automating the detection of a failure for automated generation of a pre-defined work-order candidate.

Assuming, first, that RCM principles are employed for the identification of dominant failure modes to which enabling CBM technology can be applied, and second, that the technology being inserted is both applicable and effective, other issues need to be considered. Most significantly among these are information technology (IT) interface requirements and bandwidth limitations.

The NAVSUP MHM – S&RL initiative

As sponsored by the Naval Supply Systems Command (NAVSUP), the Machinery Health Monitoring, Sense and Respond Logistics (MHM – S&RL) system was designed to enable and demonstrate autonomous initiation of a technically validated, pre-formatted work-order candidate, populated with associated parts and related material. The work order trigger is based on the automated recognition and validation of a predefined failure mode on a machine of interest, resulting in actionable information being passed up-line to legacy maintenance and logistics systems.

MHM-S&RL is focused on demonstrating this capability on the GSS 200 STAR Low Pressure Air Compressor (LPAC), a Navy design manufactured by both Dresser-Rand and Rix Industries. Failure modes are detected and processed using RLW Inc.'s S2NAP® technology interfaced with legacy shipboard applications (ICAS, PMS SKED, and NTCSS suite). MIMOSA-based software adapter interfaces were developed under this project between S2NAP and ICAS, as well as between ICAS and PMS SKED.

The team

MHM – S&RL interfaces with multiple applications and networks. No single entity has all of the required expertise to develop the technology and interfaces. Under sponsorship of NAVSUP's Command Science Advisor, the engineering group RLW assembled a multidisciplinary team as shown in Table 1.

Additionally, by way of acknowledgement, the Navy organizations listed in Table 2 also are involved in this initiative, either by lending support, defining requirements or

Ship configuration data matters. The capability described here is dependent on accurate configuration data from hull to hull.

TABLE 1. NAVSUP MHM – S&RL TEAM

Company / Vendors/ Organizations	Role
RLW, Inc.	Prime program mgmt., S2NAP® developer, systems engineering, systems integration
Uii	Supply & logistics SME, program support
Dresser-Rand	GSS-200 STAR LPAC OEM – rebuild of LBES STAR LPAC
Penn State University Applied Research Lab	S2NAP® Algorithm development
DEI Group	MIMOSA-based application adapter development, ICAS SME
Antech Systems	SKED application, PMS system SME
Fortress Technologies	FIPS 140-2 validated gateway vendor
Value Point Networks	Wireless access point vendor
Naval Surface Warfare Center, Carderock Div., Philadelphia Detachment	ICAS SME, application integration, Land Based Engineering Site support

TABLE 2. ORGANIZATIONAL INTERFACES

Organization	Role
NAVSEA (SEA 04RM)	Access to Integrated Class Maintenance Plan (ICMP), Planned Maintenance System (PMS) data, functional architecture validation, SKED application
NAVSEA (SEA 05Z53)	POC for Ship Change Documentation (SCD) process, functional architecture validation
Commander Naval Surface Forces (CNSF N43)	Access to USS BATAAN for LPAC run data
NAVSEALOGCEN Det	Demonstration 'U Card' set development
NAVSEA (PMS 400 FT)	Ship Change Documentation review for DDG demo
SPAWAR Codes 150/151 and SPAWARSYSCEN Norfolk	MOA for Navy Tactical Command Support System (NTCSS) applications suite and software/test database installation
NAVSEA (SEA 03) Distance Support Office	NTCSS suite MOA signatory
NAVSEA, Naval Surface Warfare Center, Crane Division – Distance Support Innovation Lab	Security vulnerability assessment and Integration testing
Navy Inventory Control Point (NAVICP) Mechanicsburg PA	Allowance Parts List (APL) and Secondary Item support

providing data, technical reviews and comments in support of project objectives. Table 2 illustrates the imperative to involve the entire spectrum of fleet, maintenance and logistics organizations in development and demonstration projects such as MHM – S&RL.

The system

The MHM – S&RL System is a technology development and applications integration effort in support of Navy CBM. It is designed to automatically generate work-order candidates based on objective evidence of need for maintenance, as determined by intelligent machine monitoring.

For a planned shipboard implementation, machine data for two individual LPACs in the same machinery space will be monitored by the S2NAP- embedded software device via both sensors and the LPACs' control system. A health assessment is made based on this data, and if a predefined failure mode is recognized, an appropriate fault message is sent upstream, either using wireless 802.11b or wired Ethernet to ICAS. Raw sensor data also is passed

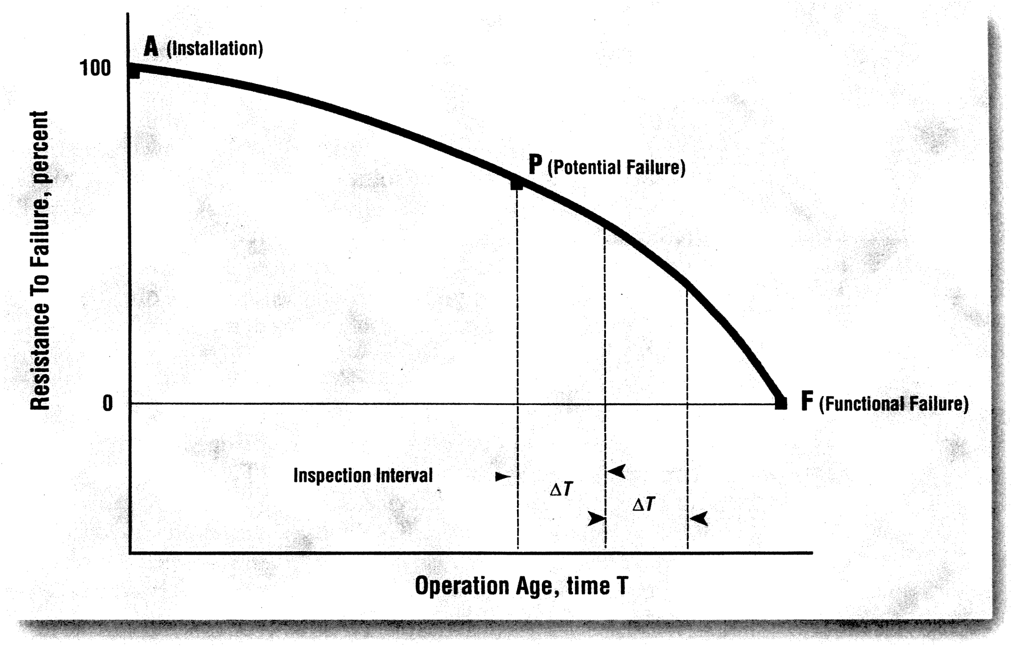

Fig. 1. Potential failure vs functional failure (adapted from Nowlan & Heap, p.51)

TABLE 3. STAR LPAC FAILURE MODES OF INTEREST

Number	Failure Mode Description
1	Clogged Water Injection Filter
2	Clogged Muffler
3	Relief Valve Actuation Failure (Tank)
4	Clogged Air Inlet Filter
5	Machinery Alignment - Coupling / Shaft
6	Clogged Water Inlet Strainer
7	Solenoid Valve Actuation Failure (Injection)
8	Solenoid Valve Actuation Failure (Unloader)
9	Compressor Bearings Worn
10	Heat Exchanger Fouled

to ICAS for display and trending. ICAS in turn, via an API, triggers a preformatted work-order candidate in OMMS NG, complete with required parts and the material (*e.g., tools and consumables*) necessary to effect the repair and cue the applicable work center via the SKED application utilizing the MIMOSA software adapter.

The dominant, most-likely-to-occur, failure modes of the STAR LPAC identified by the MHM – S&RL System were determined through detailed analysis of 3-M History, a recent Type Commander Air Compressor Reliability Study and existing integrated class maintenance plan (ICMP) "Qualified" repair tasks (Q tasks). These failure modes were then validated through interviews with auxiliary-machinery work-center sailors aboard the USS BATAAN (LHD-5). The failure modes of interest are listed in Table 3.

Each failure mode of interest (as listed in Table 3) is associated with current ICMP tasks and/or maintenance requirement cards (MRCs). Among the factors in their selection was consideration of the capability to realistically simulate occurrence of the failure in a demonstration environment. If a failure mode cannot be simulated, then there is little point in designing that failure into the demonstration system. This is a fact of life for development and demonstration of machinery health monitoring capabilities.

System operation

The MHM – S&RL System will communicate failure data from the S2NAP, integrated with the LPACs, to the ship's Fiber Optic Data Multiplexing System (FODMS) Local Area Network (LAN), No single entity has all of the required expertise to develop the technology and interfaces.

either via wired (Ethernet) or wireless (802.11b). Any wireless solution will incorporate the FIPS-140-2 security standard.

The MHM – S&RL System also is applying the Machinery Information Management Open Systems Alliance (MIMOSA) standard as a software interface adapter to legacy applications onboard the ship for this demonstration. Specifically, the MIMOSA-based software adapter will enable interfacing between the S2NAP device and ICAS, as well as between the ICAS and SKED applications.

The demonstration system is currently operational at the Land Based Engineering Site (LBES) in Philadelphia, PA. The initiative will conclude with a shipboard test in Spring of 2006, potentially associated with an ongoing Distance Support remote monitoring experimentation initiative. In order to demonstrate the system, additional hardware will be installed onboard ship, along with required software interfaces.

In the Main Engine Room #2 (MER2), additional sensors (pressure sensors and accelerometers) and S2NAP devices will be installed on two LPACs (LPAC #2 and LPAC #3). The S2NAP will receive data directly from these added sensors, as well as from the LPACs' Programmable Logic Controller (PLC). A network access device will be located in MER2 connected to the ship's FODMS network to enable communications with ICAS. This network device will either be a wireless access point or an Ethernet switch, depending on the configuration allowed by the ship.

A translator is used to pass data between the Linux-based S2NAP device and Windows-based shipboard applications. This device is being added to avoid software installations on other shipboard computers for this demonstration which would otherwise be required to facilitate communications; the translator allows for all of the software to reside on a single computer. This device can be located anywhere on the FODMS network. Its eventual location will be determined in consultation with the cognizant installation authority.

The flow of data from the machine through legacy shipboard applications is shown in Fig. 2, which reflects the network architecture that will be implemented at the LBES in preparation for the shipboard demonstration.

The SKED application currently resides on the IT21 network and is accessible via ICAS. This is the only bridge between the FODMS and the IT21 LANs.

Antech Systems developed a demonstration release of SKED 3.1 to support this project. A pre-defined set of 'U-Cards' (*standardized "Unscheduled Maintenance" cards emulating current MRCs*) corresponding with the principal failure modes was developed by NAVSEALOGCEN (Norfolk Detachment). The U-Cards are integrated into the demonstration version of the SKED application. They will be triggered upon receipt of appropriate information from ICAS through the MIMOSA interface.

The U-Cards also will identify parts and material (e.g., consumables and tools) required to complete each specific maintenance task.

In addition to U-Cards, the system will trigger a pre-defined standardized work-order candidate (Form 4790-2K) for the applicable failure mode. This work-order candidate will then be routed to the Current Ships Maintenance Project (CSMP) through the OMMS-NG application.

A MIMOSA interface to ICAS has been implemented in order to have failure modes that are already recognized by ICAS (*i.e., clogged water injection filter – FM1, and fouled heat exchanger – FM10*) passed by ICAS to SKED. Remaining failure modes (FM2-FM9) recognized by S2NAP then will be passed to ICAS for real-time display and for work -ordercandidate triggering in OMMS NG.

Projected benefits

There are many potential benefits to be obtained from the MHM – S&RL project. On the maintenance side, the time required for watch standers to take equipment readings will either be eliminated or substantially reduced by the application of sensors and remote

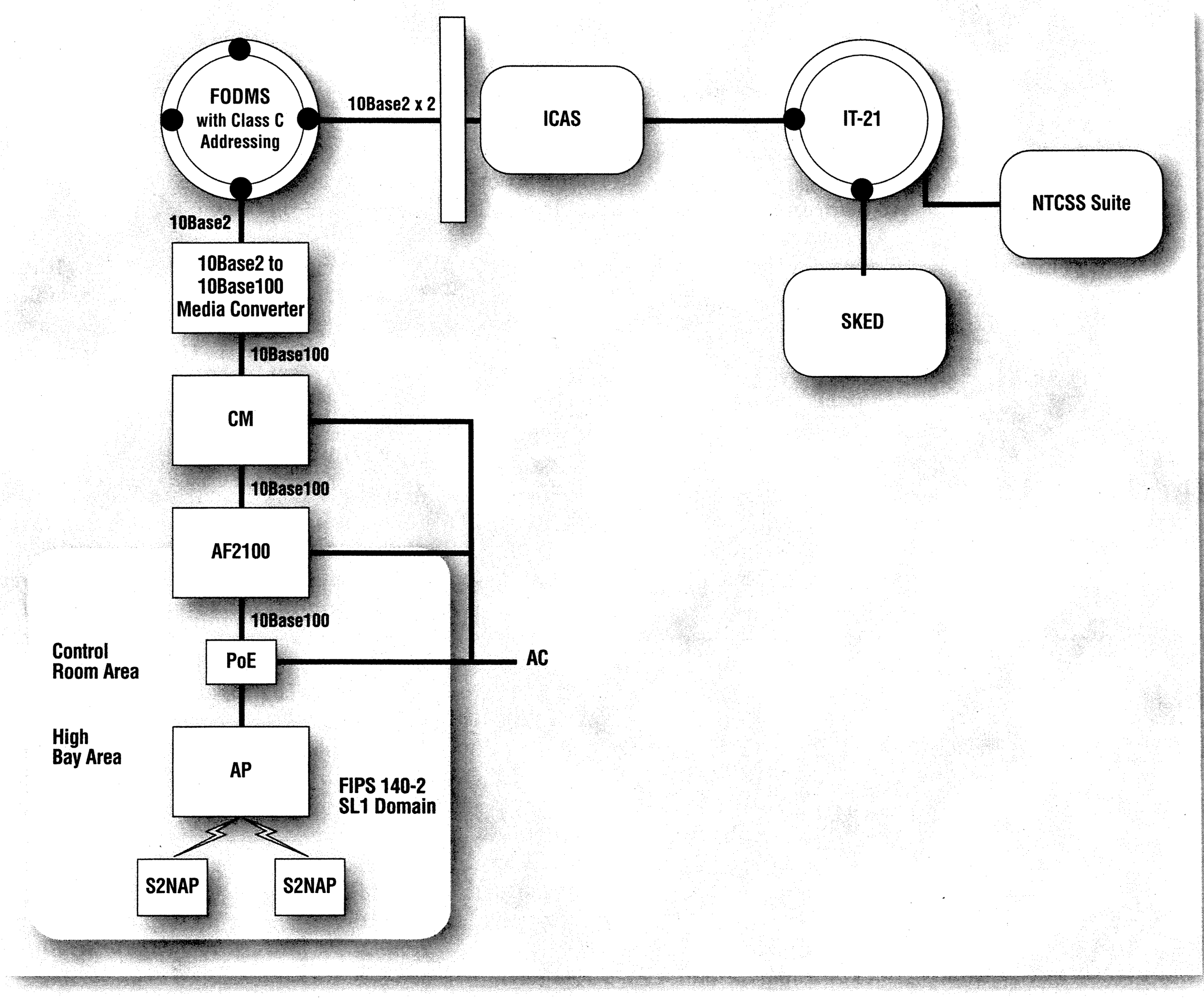

Fig. 2.
NAVSUP MHM – S&RL network architecture

monitoring. Additionally, some level of reduction is anticipated in the amount of scheduled (*planned*) maintenance required for the target equipment. There also will be some time savings from the automatic generation and management of 3-M documentation.

On the supply side, the obvious benefit is that costly investment in large quantities of onboard spare parts can potentially be reduced. With planned maintenance reduced, the amount of parts and tools required to accomplish scheduled maintenance actions should also decrease.

Finally, the amount of time required by shipboard maintenance and supply personnel to conduct technical research to identify required repair parts will diminish as this information is automatically provided on the U-Card associated with the pre-defined failure mode.

To summarize

At time of publication, this project is in the land-based demo phase. The associated Ship Change Documentation (SCD #558) is in the SHIPMAIN process for technical evaluation and the System Security Authorization Agreement (SSAA) process has been initiated. Additionally, the S2NAP platform has been evaluated for suitability to support the Distance Support initiative and is in the FIPS 140-2 validation process for wireless implementation.

Future enhancements to this system planned for FY06 include: incorporating the evolving Ships' Material Condition Model or "Corona Model"– Functional Index Numbers (FINs) and Equipment Operational Capability (EOC) values for equipments and failure modes; and follow-up fleet demonstration onboard an

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acquisition platform, most likely in the LPD-17 class. Furthermore, integration with ICAS's Integrated Performance Analysis Reports (IPARs) will be explored.

Ship configuration data matters. The capability described here is dependent on accurate configuration data from hull to hull. We know that the required level of accuracy does not exist, today. Perhaps this level of accuracy will become available through efforts such as Navy ERP and development of the Corona model.

Network security is a big deal – and getting bigger. The Distance Support Innovation Lab at Naval Surface Warfare Center,, Crane Division, provided invaluable assistance in running a security vulnerability assessment on the S2NAP platform. The platform was subsequently tweaked, and it is now deemed suitable for shipboard network implementation.

In general, advances made and lessons learned under projects like this will be made available to progressive programs such as the DDG Modernization Program, the ICAS Technology Refresh initiative, and acquisition (transformation) programs such as LPD-17, LCS, DD(X) and Navy ERP.

Tightly coupling maintenance requirements and readiness imperatives with the supporting supply chain is a future state that is achievable through continued investment, experimentation, demonstration and fielding of enabling technologies. By employing and leveraging emerging technology, visions such as BLUE SKY can evolve into reality.

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